BB
CERN
BIBLIOTHEC
22 JUN 1987

TRI-PP-87-7
Feb 1987

- 2 -

TRI-PP 87-7
9

Search for the shape isomeric gamma decay in muonic uranium

S. AHMAD¹, G.A. BEER, B.H. OLANIYI² and A. OLIN¹

University of Victoria, P.O. Box 1700, Victoria, B.C.,

Canada V8W 2Y2

S.N. KAPLAN and A. MIRESHGH³

University of California and Lawrence Berkeley Laboratory,

CA 94720, U.S.A

J.A. MACDONALD

TRIUMF, 4004 Westbrook Mall, Vancouver, B.C., Canada V6T 2A3

and

O. HÄUSSER

Simon Fraser University, Burnaby, B.C., Canada V5A 1S6

(Submitted to Canadian Journal of Physics)

Index: 25.85

-
- ¹Present address: TRIUMF, 4004 Westbrook Mall, Vancouver, B.C.
Canada V6T 2A3.
²Present address: University of Ife, Nigeria.
³Present address: University of Isfahan, Iran.

CERN LIBRARIES, GENEVA

CM-P00068260

Abstract

A search for the gamma decay of nuclear shape isomers excited by the atomic cascade of a negative muon has been undertaken in ²³⁶U and ²³⁸U. No candidate gammas have been found with yields greater than 0.2% per stopping muon. Muon capture lifetimes in ²³⁵, ²³⁶, ²³⁸U are also reported.

1. Introduction

In the atomic cascade of a muonic atom formed in an actinide nucleus there is a finite probability of a radiationless (1,2) muonic transition that excites a shape isomeric state (3-6) characterized by increased nuclear deformation. Decay of the shape isomeric state may occur by tunneling through either the inner or the outer barriers of a double-humped fission barrier (7). Penetration of the outer barrier leads to delayed isomeric fission, whereas tunneling through the inner barrier is followed by gamma de-excitation to the ground state through levels in the inner potential well. Calculations predict a higher outer than inner barrier for nuclei having $Z < 94$, which suggests a more penetrable inner barrier for lower Z actinides (7). Shape isomers with lifetimes of about 165 ns in ^{236}U and 290 ns in ^{238}U have been observed in normal uranium atoms through the fission decays, whereas searches for the gamma decay mode have yielded inconsistent results (8-12). Searches have also been made for shape-isomeric gamma decay mode of muonic uranium (4,5,13,14). Evidence of such decay in ^{238}U at a yield of 0.5%/muon stop was reported by Fromm et al. (5). The 12 ± 2 ns lifetime of the muonic shape isomer was attributed to the reduction of the potential barrier due to the presence of the 1s muon. In view of this interesting result, a measurement with greater sensitivity was undertaken for the gamma decay mode of muonic ^{236}U and ^{238}U shape isomers.

2. Experimental method

The experiments were performed using the electrostatically

separated negative muon beam from the TRIUMF M9 stopped π/μ channel (15). A schematic of the experimental setup is shown in Fig. 1. Absorber D was used to slow the muons and to stop contaminant pions in the beam. The thickness of the absorber was adjusted to maximise muon stops in the uranium target. The uranium targets were 1.7 gm/cm^2 , $>99.5\%$ enriched (^{238}U); 2.0 gm/cm^2 , $>95\%$ enriched (^{236}U); and 0.8 gm/cm^2 , $>95\%$ enriched (^{235}U). The muon stop signal was obtained from a conventional $\text{S}_1\text{S}_2\text{S}_3\text{S}_4$ scintillator telescope. In addition, a large pulse (signifying a slow muon) was required in the thin scintillator S_3 immediately upstream of the uranium target (T). Contaminant pions and electrons in the beam were vetoed in the stop signal by a cut on the beam time of flight in the channel. Events for which two muon stops were registered within about 300 ns were rejected.

In an early run, gamma rays were detected by a large volume (15%) intrinsic germanium spectrometer and seven NaI(Tl) scintillators (five $7.6 \text{ cm} \times 7.6 \text{ cm}$ and two $5 \text{ cm} \times 5 \text{ cm}$). Later runs were performed using a 20% 80 cm^3 Ge(Li) , a 10% 40 cm^3 intrinsic Ge and three $12.7 \text{ cm diam} \times 15.2 \text{ cm long}$ NaI detectors. Both the energy and the time of the gamma rays following a muon stop were recorded on tape via CAMAC by a PDP 11/34 computer. Gamma ray energies were calibrated using ^{60}Co and ^{24}Na sources and the measured values of muonic ^{238}U x rays reported by Coté et al. (18).

3. Data analysis and results

The energy and time information from the Ge and NaI detec-

tors was used to generate energy histograms with different time cuts. The energy histogram corresponding to a prompt time cut exhibits the muonic x ray transitions as shown in Fig. 2.

Delayed gamma events can result from processes such as nuclear muon capture, spin isomer deexcitations of both the target and the fragments produced from muonic prompt fission (16) and the decay of the shape isomer. Nuclear muon capture can occur either in the ground state or in the shape isomeric state of the target nucleus or in one of the fission fragments. Delayed gammas can also arise from the capture or inelastic scattering of neutrons produced in the μ^- capture process. Among all these processes, only the back decay gammas from the shape isomer are always followed by gamma rays with a muon capture lifetime.

To suppress the gamma background, a delayed coincidence with a secondary gamma ray was required as in reference 5. Considering the capture lifetime in uranium of around 80 ns, the following condition

$$120 \text{ ns} > t_{Na} - t_{Ge} > 20 \text{ ns}$$

was demanded, where t_{Na} and t_{Ge} were the recorded times after the muon stop of the NaI and Ge detector signals respectively. Energy spectra of the delayed gammas were generated with time cuts appropriate to isomer lifetimes of 12-70 ns.

The program GAMANL (17), which employs a Fourier transform (14,17) data smoothing technique was used to identify the peaks in the Ge spectra and to determine their centroids and areas. The gamma ray yield per muon stop $Y(E)$ for a peak at energy E was normalized using the known muonic x ray intensities (18).

A Monte Carlo simulation technique was developed (14) to determine the probability as a function of energy and yield with which a gamma ray would be identified using GAMANL. Peaks in simulated data could be found with 90% confidence if $\frac{\sigma A}{A} = \frac{\sqrt{A+2B}}{A} = 0.3$ where A and B are the total counts in the peak and the background summed over a region of $0.5 * \text{FWHM}$ of the peak. The yield limit at the 90% confidence level is shown in Fig. 3. A typical ^{238}U suppressed delayed gamma spectrum is shown in Fig. 4.

We conclude that at an effective sensitivity of 0.2% per muon stop and at 90% confidence level no back decay gamma component from the shape isomeric states for the energy range of 2 to 3.5 MeV in muonic ^{236}U and ^{238}U was observed. In the case of ^{238}U , our finding is contrary to the results of the Dubna group (5) who reported delayed gamma rays at 2215 and 3131 keV with a yield of 0.5% per muon stop*. This result is not very sensitive to the assumed isomer lifetime provided that the appropriate timing region is analysed; the yield limits for $\tau = 70$ ns are slightly lower than shown in Fig. 3.

The yield limit for the back decay gamma branch (Y_γ) can be translated into an upper limit for the probability of the shape isomer excitation (P) per stopping muon, using the relation

*These gamma rays were ascribed to transitions from a shape isomeric state, energetically shifted due to the muon binding energy (2), with an excitation energy of 3176 keV and lifetime of 12 ns, to the 2^+ levels of the γ vibrational and ground state band.

$$P = \frac{Y_Y}{\lambda_C^i + \lambda_Y^i + \lambda_f^i} \quad (1)$$

where λ_C^i is the muon capture rate, λ_Y^i is the back decay rate and λ_f^i is the fission rate from the isomeric state. Substituting some typical values (5) $\lambda_Y^i = 2.08 \times 10^7/\text{sec}$; $\lambda_f^i = 6.4 \times 10^2/\text{sec}$ and $\lambda_C^i = 1.33 \times 10^7/\text{sec}$ and using our value of $Y_Y < 0.2\%$ per μ^- stop, we get $P < 0.3\%$ per muon stop. Radiationless transitions amount to about 25% of the muon cascade (19), so that from the upper limit for P a limit of $< 1.2 \times 10^{-2}$ can be deduced for the excitation of the shape isomeric state during a radiationless transition. This is in good agreement with a recent calculation (6). However a measurement of the reaction $^{235}\text{U}(d,p)^{236}\text{U}$ found that $\Gamma_Y/\Gamma_f < 1.5$ for the 165 ns isomer at 2.35 MeV (12), so it is possible that the non-observation of back-decay on our experiment is due to the low probability for such deexcitation.

In addition, we have also studied the time distribution of gammas measured with the NaI detectors in coincidence with prompt muonic K_α x rays (shown in Fig. 2) measured with a Ge detector. In principle, this should give the true muon capture lifetime since the contributions from the prompt fission fragments (produced by non-radiative transitions) are eliminated. It is also probable that some of the gamma rays are from secondary interactions in the target of neutrons produced in muon capture, but the time dependence would still follow that of the capture process. Lifetimes thus measured were: 71 ± 2 ns (^{235}U), 70 ± 2 ns (^{236}U)

and 78 ± 2 ns (^{238}U). The ^{235}U and ^{238}U , results are in good agreement with previous measurements (16). No previous measurement for ^{236}U has been reported.

Acknowledgements

One of the authors (S.A.) is grateful to the Canadian Commonwealth Fellowship Committee and to the Government of Bangladesh for kind support. This experiment was supported by the Natural Science and Engineering Research Council of Canada under grant IEP-11 and by the U.S. Department of Energy under contract W-7905ENG48.

References

1. J.A. WHEELER. Rev. Mod. Phys. 21, 133 (1949).
2. D.F. ZARETSKI and V.M. NOVIKOV. Nucl. Phys. 28, 177 (1961).
3. S.D. BLOOM. Phys. Lett. 48E, 420 (1974).
4. S.N. KAPLAN, J.A. MONARD and S. NAGAMIYA. Phys. Lett. 64E, 217 (1976).
5. W.D. FROMM et al. Nucl. Phys. A278, 387 (1977).
6. J. DE KAM and G. WOLSCHIN. Phys. Lett. 125B, 109 (1983).
7. For example S. BJORNHOLM and L.E. LYNN. Rev. Mod. Phys., 52, 725 (1980); C.F. TSANG and S.G. NILSSON. Nucl. Phys. A140, 275 (1970).
8. J. KANTELE et al. Phys. Rev. Letts. 51, 91 (1983).
9. J. DREXLER et al. Nucl. Phys. A411, 17 (1983).
10. J. KANTELE et al. Phys. Rev. 29C, 1693 (1984) and references there in.
11. P.A. RUSSO, J. PEDERSEN and R. VANDENBOSCH. Nucl. Phys. A240, 13 (1975).

12. P.A. BUTLER, R. DANIEL, A.D. IRVING, T.P. MORRISON, P.J. NOLAN and V. METAG. J. Phys. G 6, 1165 (1980).
13. S. AHMAD et al. Proc. Int. Conf on Nucl. Phys. Berkeley, CA USA 1, 369 (1980).
14. A. MIRESHCHI PhD thesis, Univ. of California, Berkeley 1982.
15. N.M.M. ALQAZAZ et al. Nucl. Inst. Meth. 174, 35 (1980).
16. S. AHMAD et al. Can. J. Phys. 64, 665 (1986) and references there in.
17. T. INOUE, T. HARPER and N.C. RASMUSSEN, Nucl. Inst. Meth., 67, 125 (1969).
18. R.E. COTÉ et al. Phys. Rev., 179, 1134 (1969).
19. E. TELLER and M.S. WEISS. Lawrence Livermore Laboratory report UCRL-83616 (1979).

FIGURE CAPTIONS

Fig. 1 Schematic diagram of the experimental set up for a) early run, b) later run. (S_1 , S_2 , S_3 & S_4 are beam scintillators; Ge are the Germanium detectors, 1, 2, ... 7 are the NaI detectors.)

Fig. 2 A typical prompt gamma spectrum of $\mu^- 238\text{U}$.

Fig. 3 Yield limits at 90% confidence level for detecting a back decay gamma having isomer lifetime of 12 ns. These limits are determined from suppressed gamma events occurring from 7.5 to 22.5 ns in 238U and from 7.5 to 27.5 ns in 236U . The 236U background spectrum fell about five times faster than that of 238U which affects the sensitivity curve.

Fig. 4 A typical delayed and suppressed gamma energy spectrum of $\mu^- 238\text{U}$ for the time window of 10 to 25 ns after muon stop. The inserts show the regions where gammas were previously reported (5) at expanded scale.

Fig. 1

Fig. 3

Fig. 2

Fig. 4